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Energy efficiency and low carbon enabler green IT framework for data centers considering green metrics

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ABSTRACT

The increasing demand for storage, networking and computation has driven intensification of large complex data centers that run many of today's Internet, financial, commercial and business applications. A data center comprises of many thousands of servers and can use as much energy as small city. Massive amount of computation power is required to drive and run these server farms resulting in many challenging like huge energy consumptions, emission of green house gases, backups and recovery; This paper proposes energy efficiency and low carbon enabler green IT framework for these large and complex server farms to save consumption of electricity and reduce the emission of green house gases to lower the effects of global warming. The framework uses latest energy saving techniques like virtualization, cloud computing and green metrics to achieve greener data centers. It comprises of five phase to properly implement green IT techniques to achieve green data centers. The proposed framework seamlessly divides data center components into different resource pools and then applies green metrics like Power Usage Effectiveness, Data Center Effectiveness and Carbon Emission Calculator to measure performance of individual components so that benchmarking values can be achieved and set as standard to be followed by data centers.

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1. Introduction

In recent years organizations have witnessed a global intention of employing environment friendly products and technologies to encounter global warming. Well known computer hardware and software manufacturing firms are competing to use environmentally sustainable energy efficient technologies in their products and services. Additionally, many companies and organizations are trying to experience green information technology (IT) initiatives by implementing green sustainable technologies to make their businesses environment friendly, sustainable and cost effective [1]. There has been an unprecedented increase in the level of concern regarding climate change and environmental sustainability. Businesses are under increasing pressure from customers, shareholders and users to propose legislative changes to improve environmental credentials. Likewise, the environmental impact of information technology under the banner of "Green IT" has started being discussed by academia, media and government. IT professionals are expected to play significant roles in bringing Green IT to organizations, provided they are prepared, have developed or developing necessary capabilities to lead and support sustainability initiatives [2]. The progress of information and communication technology (ICT) based businesses and social practices have transformed many, economies into e-economy and businesses into e-businesses. Technology has the potential to create sustainable businesses and societies with grim and green economics. ICT is increasingly playing critical role in transforming and generating economic opportunities. On the other hand, global warming and climate change coalescing with limited availability and rising cost of energy are posing serious challenges for the sustainability of the global digital economy [2].

One of the areas of IT businesses where environmental sustainability is becoming imperative is data centers. They form the backbone of a wide variety of services offered via the Internet including Web-hosting, e-commerce, social networking, and a variety of more general services such as software as a service (SAAS), platform as a service (PAAS), Internet as a service (IAAS), grid and cloud computing [3]. Data center refers to business facilities containing large ICT infrastructure platform (ICTP), cooling and power delivery equipments, servers and storage devices to store, process, and exchange digital data and information [4]. They are found in nearly every sector of the economy, ranging from financial services, media, high-tech, universities, government institutions, and many others use and operate them to aid business processes, information management and communication functions [5]. Internet and business applications are increasingly being moved to large data centers that hold massive server and storage clusters. Massive amount of computation power is required to drive these large and complex systems, resulting in many issues and challenges like huge energy consumption by different data center components like servers and storage devices and emissions of green house gases very hazardous for global warming and environmental sustainability.

In recent years, commercial, organizational and political landscape has changed fundamentally for data center operators due to the confluence of apparently incompatible demands and constraints. The energy use and environmental impact of data centers has recently become a significant issue for both operators and policy makers. Public perception of climate change and environmental impact has changed substantially, delivering real commercial impacts for corporate environmental policy and social responsibility. Unfortunately, data centers represent a relatively easy target due to very high density of energy consumption and ease of measurement in comparison to other, possibly more significant areas of IT energy use. Policy makers have identified IT, specifically data center energy use as one of the fastest rising sectors [6].

The increasing demand for storage, networking and computation has driven the demand for large data centers, the massive server farms that run most of today's Internet, financial, commercial and business applications. A data enter comprises of many thousands of servers and can use as much energy as small city [7]. All data centers are predominantly occupied by low cost underutilized volume servers called x-86 servers for performing most of the processing and services to end users. Microsoft is adding 20,000 servers monthly to their server farms to meet ever growing demands of users and businesses [13]. These servers consume a lot of energy and power and emit green house gases in the form of CO_2. In an average server environment, 30% of the servers are "dead" only consuming energy without being properly utilized; their utilization ratio is very low only about 5–10% [8]. Research is going on to create techniques and opportunities to make these devices more useful and energy efficient. There is a strong need to develop and implement energy efficiency mechanism to reduce server footprints and energy consumptions [8,14].

As corporations look to become more energy efficient, they are examining their operations more closely. In order to handle the sheer magnitude of today's data, data centers have to use much more power as they become larger, denser, hotter, and significantly more costly to operate. An EPA report to Congress on servers and data center energy efficiency estimates that U.S data centers consume 1.5% of total U.S electricity consumption for a cost of $4.5 billion [9]. From the year 2000 to 2006, data center electricity consumption has doubled in the U.S and is currently on a pace to double again by 2011 to more than 100 billion kWh, equal to $7.4 billion in annual electricity costs [7]. These data centers not only consume huge energy but also major contributor towards company's electricity bill [10]. Gartner warns that today's data centers are big energy consumers and are filled with high density power hungry IT equipments, if data center managers remain unaware of these energy problems, they will most probably run the risk of doubling their energy costs between 2005 and 2011 [11]. If energy costs continue to double every five years, they will substantially increase to 1600% between 2005 and 2025 [12].

According to a report released by International Data Corporation (IDC) in September 2008, almost half of 459 European companies surveyed had put in place a strategy for incorporating green IT and cost saving as main drivers for going green [15]. Like the energy costs, energy use in data centers is also doubling every five years [11]. Considering delayed capital investments, there could be no more emphasis on energy efficiency as is becoming a key measure of operational effectiveness for data centers [9]. One of President Obama's primary platforms is the support for green energy. On his agenda is a goal of having all new buildings carbon neutral by 2030, and also establish a national goal of improving new building efficiency by 50% and existing building efficiency by 25% during the next decade to reach the 2030 goal [16].

Gartner emphasizes that ICT industry is responsible for about 2% of global CO_2 emissions almost equivalent to the aviation industry [18]. An EPA report to U.S congress in 2007 emphasizes that, current energy consumption in data centers is leading to an annual increase in the emission of CO_2 (green house gases) from 42.8 million metric tons ($MMTCO_2$) in 2007 to 67.9 $MMTCO_2$ in 2011 [9]. Intense media coverage has raised the awareness of people around the globe for climate change and green house gas effect on global warming. Besides the environmental concern, businesses have begun to face risks caused by being non-environmentally friendly. Reduction of CO_2 footprints is an important problem that has to be addressed in order to facilitate further advancements in computing systems. The survey results from InfoTech's (2008) international survey of Asia, Europe, USA and the rest of the world shows that more than 50% of the survey respondents were strongly concerned about global warming and its effect on climate change [19]. 144 nations signed

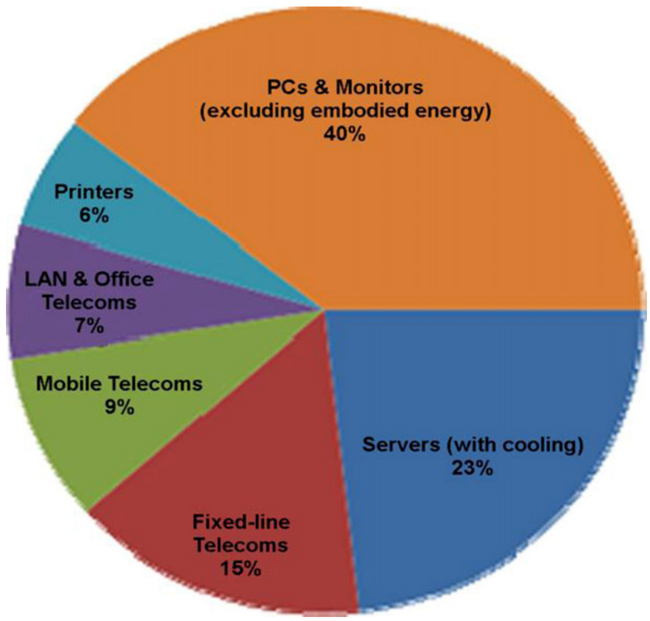

Fig. 1. Estimated ICT CO_2 emissions.

and began implementing Kyoto accords, to reduce (GHS) emissions by 29%.

Fig. 1 shows an estimate of CO_2 emissions for each ICT category. It is more than likely that energy consumption and carbon emissions will continue to increase in coming years. According to the SMART 2020 study, CO_2 emissions from ICT are increasing at a rate of 6% per year and with such a growth rate they could represent 12% of worldwide emissions by 2020 (The Climate group Smart, 2010) [26].

Electricity used by IT equipments has been a subject of intense interest since the first ENERGY STAR specification for personal computers was released in the early 1990s [20]. The first detailed measurements of personal computer electricity use were published in the late 1980s [21] followed by estimates of total power used by office equipment [22–24] and assessments of potential efficiency improvements in that equipment [25]. The need for metrics and methods for facilitating energy consumption and efficiency is critical for green initiatives to succeed. There has been relatively little focus on metrics and models to facilitate optimizations, defining and measuring energy efficiencies at different levels in the data center, which helps designers, compare designs and identify promising energy efficient technologies [17]. There is a need for flexible, dynamic and secure Green IT framework to handle energy issues in data centers to reduce carbon footprints [77].

Green IT or Green Computing is a way towards more environment friendly and cost effective use of power and production technology. Green IT is used as an umbrella term for overlapping concepts like virtualization, cloud computing outsourcing, recycling, procurement and power management, etc. The aspiration of Green IT is focused on achieving higher energy efficiency in the use of IT devices and to increase the utilization of already installed devices in data centers. However, at the same time, organizations need to deliver new IT Services in short time considering high reliability, performance and availability requirements as important issues in supporting the business processes. To achieve these objectives IT must have a clearly defined Green IT strategy or framework tuned with business strategy and goals to be able to realize and achieve both of these objectives at the same time. IT needs to quickly and transparently translate IT Strategy to IT operational processes to ensure effective business IT alignment in most efficient way.

The research depicted in this paper highlights the importance of green IT technology for developing a framework using energy efficiency technologies and green metrics to be implemented in large tier level data centers to overcome some of the problems and issues highlighted above. The proposed energy efficiency and low carbon enabler green IT framework provides an implementation strategy for data center managers to properly implement green IT solutions in existing or new data centers to make them more energy efficient and green. The proposed framework also contains a metrics based model to categorize data center components into measurable units depending on the workloads they execute and then defines certain green metrics to measure the performance of data center in terms of energy efficiency and CO_2 emissions.

2. Problem background

The commodity price of energy has risen faster than many expectations, and now reaching to almost \$100 barrel. This rapid rise in energy cost has substantially impacted the business models for many data center operators and has already driven changes in the way data center capacity is charged for commercially. Energy security and availability is also becoming an important aspect for data center operators as the combined pressures of fossil fuel availability, generation and distribution infrastructure capacity and environmental energy policy make prediction of energy availability and cost difficult. Opposing these constraints are demands from the business consumers for increased data center services. As these demands continue to increase, these digital powerhouses are faced with several power, cooling, performance, and space constraints associate with environmental, technological, and economic sustainability issues. Improving the energy efficiency and environmental performance of data centers is therefore at the forefront of organization's actions in 'greening' their IT [28].

Increased reliance on the storage, backups, transfer, and processing of digital information throughout all aspects of society has caused significant growth in data center energy use. In U.S alone data center energy use doubled between 2000 and 2006 to about 60 billion kWh annually and is expected to continue to rapidly increase [27,28]. While growth projections made before the current economic downturn may overestimate near term growth in data center activity, a recent evaluation showed that significant growth continued at least through 2008 with data centers consuming ~70 billion kWh during that year [29]. The level of energy use corresponds to emissions of $\sim$1.21013 g y^{-1} of fossil carbon (42 Mt/y of CO_2), based on the average carbon intensity of 160 g C/kWh for US electricity production [30].

Emissions of green house gases (GHG) from aviations, shipping, Transportations, Telecommunications and manufacturing industry are rising fast, but the emissions from IT are mounting faster. Reductions achieved through the use of Green IT in key economic sectors would be five times greater than the growth in emissions from the IT sector itself. Continuous increase in these emissions from IT is projected to increase from 3% of total global emissions in 2009 to a whopping 6% by 2020 ("SMART 2020" Report in 2008 on behalf of the Global e-Sustainability Initiative) [78] (Table 1).

As businesses become more dependent upon IT services, the requirements for availability and continuity of services has increased, multiplying the equipment requirements. A failure to understand the relationship between the falling capital cost of IT equipment and the rising costs of housing and powering it is also creating capacity and financial problems for many operators. Ensuring a secure energy supply, preserving the environment and protecting the climate are central challenges facing today's world. Environmentally friendly technologies are the key to sustainable economic activity. In order to optimize the use of resources across

Table 1
CO_2 emissions (carbon foot print) climate group and the global e sustainability initiative SMART 2020.

World	Emissions 2007 $MtCO_2e$	Percentage 2007	Emissions 2020 $MtCO_2e$	Percentage 2020
World	830	100%	1430	100%
Server farms/data centers	116	14%	257	18%
Telecom infrastructure and devices	307	37%	358	25%
PCs and peripherals	407	49%	815	57%

the entire spectrum of global value chains, it is essential to tap the full potential of technology. According to Uptime Institute, 3 year energy cost of Server will exceed its purchase cost [32].

The energy consumed by various computing facilities creates different monetary, environmental and system performance concerns. A recent study on power consumption of server farms shows that in 2005 the electricity use by servers worldwide including their associated cooling and auxiliary equipments cost US$7.2bn. It also indicates that the electricity consumption in that year had doubled as compared with consumption in 2000 [28] (Fig. 2).

The scope of energy efficient design is not limited to main computing components like processors, storage devices, network devices and virtualization facilities, but can expand to a much larger range of resources associated with computing facilities including auxiliary equipments, water used for cooling and even physical/floor space these resources occupy [33].

The amount of electricity used by servers and other Internet infrastructure has become an important issue in recent years. One of the weaknesses in the literature on data center electricity use has been the lack of credible estimates of the aggregate power used by all servers and associated equipment in the U.S. and the world. The data on the floor area and power densities of data centers are anecdotal and limited by the proprietary nature of such data in most companies. Data on the installed base of servers are also closely held by the companies who track it, and server technology continues to change rapidly, necessitating constant updates to measurements of power used by particular server models [28].

In 2006, US data centers used about 61 billion kWh; i.e., 1.5% of the 4 trillion kWh consumed in total. This is equal to the amount of energy used by 5.8 million average US households (5% of all households). This power resulted in 37 million metric tons of CO_2, or 6% of 5.9 billion metric tons released from all sources in whole world. This electricity cost US $4.5 billion and required a peak load capacity of about 7 GW, more than double the level of consumption in 2000. Peak load capacity is expected to double again by 2011 to 12 GW, requiring the construction of 10 additional 500 MW power plants [7]. Given the rapid, unabated rise in electrical power consumption and the associated financial and environmental costs, data center operators realize that the established practice of running large numbers of significantly underutilized servers is no longer acceptable, and are eager for energy-saving solutions.

Fig. 3 compares the purchasing dollars spent on new servers with the power and cooling cost since 1996 and projects those numbers until 2011 [34]. According to IDC, the cost to power the servers will exceed the cost of servers by the next year [15].

The recent advances in hardware and software technologies including low power processors, solid state drives and energy efficient monitors have alleviated the energy consumption issue to a certain degree, a series of software approaches have significantly contributed to the improvement of energy efficiency. Traditionally, power and energy efficient resource management techniques have been applied to mobile devices. It was dictated by the fact that such devices are usually battery-powered and it is essential to consider power and energy management to improve their lifetime. However, due to continuous growth of power and energy consumption by servers and data centers, the focus of power and energy management techniques has been switched to these systems. Even though the problems caused by high power and energy consumption are interconnected, they have their specifics and have to be considered separately.

To address these business drivers is not just a matter of technology but an IT Governance approach setting the proper leadership: creating new structures and relationships; tuning the processes to cover the whole asset environmental lifecycle from the design to the disposal; and defining a new culture and attitude through the right communication and training.

2.1. Environmental impact of IT

The immense use of IT has exploded in all areas of business activities offering great benefits and convenience and irreversibly transforming businesses and societies into global world. But at the same time IT has been contributing tremendously towards the environmental problems. Unfortunately, most people including many IT professionals do not realize this. IT affects our environment in several different ways. Each stage of a computer's life from production, use to disposal presents environmental challenges. Manufacturing computers and their various electronic and non electronic components consumes electricity, raw materials, chemicals, and water, and generates hazardous waste. All these factors contribute towards environment problems. Globally, the total electrical energy consumption by data centers, servers, and computers is steadily increasing. The increase in energy consumption results in increased greenhouse gas emissions as most of the electricity is generated by burning coal, oil, or gas. Countless old computers and other electronic hardware, which contain toxic materials are discarded within a couple of years after purchase, end up in landfills, polluting the earth and contaminating water. The increased number of computers in use and their frequent replacements make the environmental impact of IT a major concern. Consequently, there's increasing pressure on us to make IT environmentally friendly.

To overcome some of the environmental issues, green IT spans many focus areas and activities, including power management; data center design, layout, and location; the use of biodegradable materials; regulatory compliance; green metrics and green labeling; carbon footprint assessment tools and methodologies; and environment related risk mitigation. A growing number of IT vendors and users have begun to turn their attention toward Green IT, triggered by the imminent introduction of more green taxes and regulations; there will be a major increase in demand for green IT products and solutions. Green IT will be the hot topic for years to come, because it now becomes imperative to develop environmentally sustainable IT, from both an economic and environmental viewpoint [35].

Green IT includes hard technologies and soft systems, business policies and practices spanning the IT lifecycle from production, sourcing, building and disposal. Environmental considerations should also be embedded in policy frameworks along with operational routines, IT design features and information systems as well as values and norms of the IT human infrastructure and managerial considerations and practices. Greening IT can be undertaken to address two overarching and interrelated goals. Firstly green IT can help businesses to mitigate IT direct contribution of CO_2 emissions.

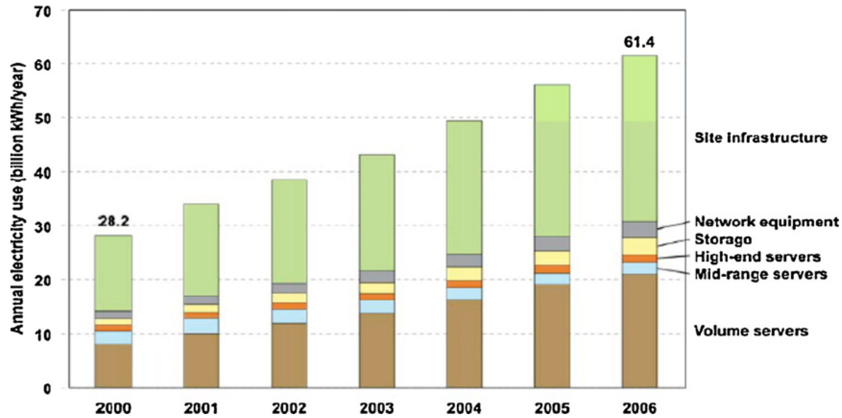

Fig. 2. Data center and server efficiency.

Source: EPA.

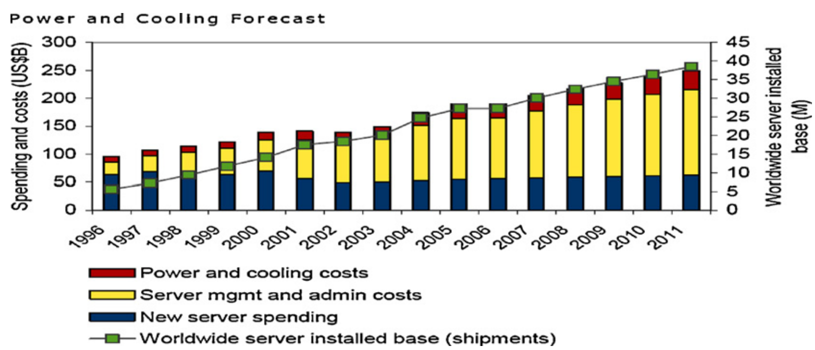

Fig. 3. Worldwide cost to power and cool server installed base, 1996–2011.

Secondly it helps businesses tackle their overall footprint that is using IT as part of the solution to reduce business's environmental footprint. The following business drivers can be identified:

1. Cost-reduction due to an efficient energy use.
2. Public image aligned to environmental concerns.
3. Environmental regulatory compliance.

To make businesses environment friendly and reducing the overall cost of ownership, green IT proposes some of the major advantages that can be achieved if green policies and frameworks based on green IT should be implemented properly. Some of these benefits are:

- Green IT reduces organizations overall energy costs.
- It prolongs or extends the life of existing data center equipments by intelligently refreshing equipments, taking advantage of energy efficiencies.
- It reduces IT maintenance activities and costs and improves overall image of the organization.
- It saves money and reduces environmental stewardship by proper disposal of waste and toxic hardware, by proposing new hardware's which are environment friendly, consume less energy and easy to dispose off.
- It reduce overall carbon footprints there by reduces global warming effects.
- It reduces the emission of CO_2, thereby reducing the respiratory problems faced by different species.
- It reduces Acid rains, smog and global climate change effects.
- It reduces the strain on the electricity grid.
- Free up space on data center floors.
- It takes advantage of pricing incentives, tax breaks and rebates offered by utilities, insurance companies and governments.
- It prepares the organization for compliance with future regulations and certifications.

2.2. Green data center

The green data center has moved from the theoretical to the realistic, with IT leaders being challenged to construct new data centers or retrofit existing ones, with energy saving features, sustainable materials and other environmental efficiencies. The green data center is an energy-efficient, dense computing ecosystem where:

- Software technologies control data growth and shrink capacity demands
- Managers use Service Level Agreements to manage energy usage
- Energy efficient computing infrastructure optimizes performance and utilization levels
- Physical plant is engineered for maximum energy efficiency

A green data center is a repository for storage, management and dissemination of data in which mechanical, lighting, electrical and computing systems are designed for maximum energy efficiency and minimum environmental impact. Data centers are one of the organizations where the Greening process should begin [36]. Green data center operations strategically aligns IT organization with, sustainable organizational objectives to achieve greater corporate social responsibility. Some of the benefits of green data center include: Lower server and Storage temperature and costs, increased system and storage reliability, density and uptime, maximizes software and hardware utilization thus lowers energy use, increased environmental and business sustainability solutions, lower carbon

emissions and limiting the effects of global warming and extending the life of data center.

2.3. Energy efficiency

Energy conservation is any behavior that results in the use of less energy. Energy efficiency is the use of technology that requires less energy to perform the same function. A compact fluorescent light bulb that uses less energy than an incandescent bulb to produce the same amount of light is an example of energy efficiency. Energy sustainability focuses on long term energy strategies and policies that ensure adequate energy to meet today's needs, as well as tomorrows. Sustainability also includes investing in research and development of advanced technologies for producing conventional energy sources, promoting the use of alternative energy sources, and encouraging sound environmental policies.

Considering the power consumption in data centers, the main problem is the minimization of the peak power required to feed a completely utilized system. In contrast, the energy consumption is defined by the average power consumption over a period of time. Therefore, the actual energy consumption by a data center does not affect the cost of the infrastructure. On the other hand, it is reflected in the electricity cost consumed by the system during the period of operation, which is the main component of a data center's operating costs. Furthermore, in most data centers 50% of consumed energy never reaches the computing resources: it is consumed by the cooling facilities or dissipated in conversions within the UPS and PDU systems. With the current tendency of continuously growing energy consumption and costs associated with it, the point when operating costs exceed the cost of computing resources themselves in few years can be reached soon. Therefore, it is crucial to develop and apply energy efficient resource management strategies in data centers.

Various types of high performance equipment are being deployed in data centers. To support these high performance requirements, data centers must provide more power for the equipment to perform efficiently and reliably. One of the strategies being investigated to improve energy use in data centers is the use of renewable energy sources to provide the required power need to operate the data center. Building data centers in those geographical areas with an abundance of renewable energy sources (solar, wind, etc.) is one option that has been explored. Another option is to avoid multiple conversions between Alternating Current (AC) and Direct Current (DC). The basic idea in this case is to do the conversion only once at the data center rather than doing it several times at various servers as is done currently [37]. The use of more power is also causing more heat to be generated by data center infrastructures. To address the heat issue, many cooling strategies are being investigated and developed. Power and cooling efficiency improvements will continue to challenge the design of next generation, energy-efficient data centers. To achieve power efficiency, we need to develop solutions not only at the system level through well-known power management solutions but also through the careful integration of hardware solutions such as asymmetric multi-core microprocessor design, efficient packaging techniques, and energy-proportional hardware designs that focus on memory and disk subsystems which can reduce the power consumption of central processing units [38].

3. Problem statement

Data Centers are plagued with thousands of servers performing the processing for businesses and end users to facilitate and accomplish large business goals. With continuous increase in businesses especially e-businesses, the need for large and complex data centers is obvious. But the problem with most of the data centers is that almost 90% of the servers remain idle most of the time performing nothing but consuming huge energy and at the same time generating enormous amount of CO_2 very hazardous for environmental sustainability and global warming. Their number is increasing data by day as the demands from end users increase. There is no mechanism available to measure the performance of already installed servers so that their utilization ratio can be increased, resulting in low consumption of energy and less emission of CO_2. The developing countries like Pakistan, which are already facing huge energy crisis and deficits to meet the demands of domestic purposes, becomes very much difficult to provide enough energy resources to these ever growing data centers resulting in overall degradation of economy of the country. IT industrial output has fallen precipitously due to current energy crisis. Therefore it becomes pertinent to have some strategies or frameworks for these large data centers so that they can cop up with ever growing demands from businesses and end users. There is a strong need for the implementation of a mechanism that properly utilizes server resources so that energy consumption can be reduced by eliminating the idle servers, also some metrics should be developed to benchmark the performance of data centers so that their energy consumption can be measured.

3.1. Related work

The Green IT movement is revolutionizing the industry with governments, regulatory bodies, policy makers, investors, product manufacturers, enterprises, and members of the public taking an acute interest in energy and environmental issues. To optimize the performance of data center in terms of energy efficiency and CO_2 reductions, G-Readiness model was proposed by Molla [39] as initiative to address environmental issues and their overall effect on organizations and global world as whole. The G-Readiness model measures the readiness of Green IT in an organization to implement green initiatives in order to achieve greener concept. The lack of definition of green IT has made it difficult to measure the effectiveness or the extent of an organization's implementation of Green ICT. As the old saying goes, you can't manage what you can't measure. And you can't measure what you can't define. Connection Research in conjunction with RMIT University in Melbourne, School of Business Information Technology has developed Green ICT Framework which is a combination of two frameworks one developed by Molla and other by Connection research. The Framework is called the Connection Research-RMIT Green ICT Framework [40]. It focuses on an organizational implementation of green IT through ICT. The Connection Research-RMIT Green ICT Framework does not specifically look into the details of data center, as it focuses on the ICT issues in organizations, in which data centers are a part of ICT. But as a whole it does not look into the details of data center specially energy efficiency and greening data centers to build environment friendly atmosphere around the globe.

Other organizations like Green Grid, Energy Star, green data center alliance and many others are trying to develop green IT frameworks specifically focusing on data center industry to reduce the emission of green house gases by properly increasing the utilization ratio of already installed resources and devices.

With the rising power dissipation of modern hardware, energy management and efficiency is becoming an important issue in system design. Especially in server systems, the cost for power supply and cooling plays a major role. Limiting the energy consumption of the hardware avoids over provisioning of power supply and cooling facilities. Furthermore, reducing the operating temperatures increases stability and reliability of the components. Most of the current hardware's feature built-in energy management tools that disable certain device features or reduce the speed during phases of low utilization. However, because the hardware is unaware of

the executed software, it cannot respond to application or user specific requirements. Therefore, research has proposed several approaches to dynamic energy management that control energy consumption in the operating system [31].

To drive energy efficiency improvements, we need benchmarks to assess their effectiveness. Unfortunately, there has been no focus on a complete benchmark, including a workload, metric, and guidelines, to gauge the efficacy of energy optimizations from a whole-system perspective. Some efforts are under way to establish benchmarks for energy efficiency in data centers [82,84] but are incomplete. Other work has emphasized metrics such as the energy-delay product or performance per Watt to capture energy efficiency for processors [79–81] and servers [83] without fixing a workload. Moreover, while past emphasis on processor energy efficiency has led to improvements in overall power consumption, there has been little focus on the I/O subsystem, which plays a significant role in total system power for many important workloads and systems.

There are many works related to job/task allocations in clusters in data centers. Some of the other techniques focus on load balancing algorithms [41,42] to balance computational work among different machines, hence improving the performance of the cluster systems called racks. Other works [43–46] focus on optimizing the computing resource usage, by using the smallest computing resource to process maximum number of valuable tasks. This work focuses on trying to use smallest amount of energy to process maximum number of tasks. In a homogeneous system, there is no difference between optimizing energy and optimizing the computing resource usage. But in the heterogeneous system, a solution of optimizing the computing resource usage may not energy efficient.

The literature has recorded many works using dynamic voltage scaling (DVS) to save energy in the real time system. In [47–51], the authors present energy aware methods to schedule multiple real time tasks in multiprocessor systems that support dynamic voltage scaling. Also using dynamic voltage scaling capability, the work in [52–54] concentrates on the problem of energy minimization for hard real time tasks that are scheduled on an identical multiprocessor platform. The authors in [55] tried to save energy using soft real time CPU scheduling for mobile multimedia systems. Considering the memory energy consumption, Merkel and Bellosa [56] describes a way of scheduling that has impact on the effectiveness of frequency scaling at saving energy. All above works concentrate on controlling directly the energy consumption of hardware by adjusting voltage. This technique can also be applied at the data center level. In fact, we integrate the voltage adjustment technique to our proposed framework in identification categorizing phase where workloads are categorized depending on their processing and execution capabilities. However, because of focusing on real time tasks on multiprocessor system, those techniques did not consider reducing the energy of active computing nodes which is an efficient method to reduce energy consumption [57].

There are some works targeted at reducing power and thus improving the performance per watt of a homogeneous as well as heterogeneous cluster running a single application [58–60]. Those works consider request distribution to optimize both power and throughput in heterogeneous server clusters. Their mechanism takes the characteristics of different nodes and request types into account. All not necessary computing nodes will be turned off. However, all of them considered single core computing nodes. The case of the cluster including different number of cores servers is not examined. Selecting suitable servers in the set of heterogeneous number of cores servers can lead to significant energy reduction. Moreover, our problem has broader scope with many applications and processes running on heterogeneous infrastructures.

The other related works focus on proposing the applications of resource on demand model [61–63] to data centers. In this model, all resources of the data center are combined in a pool and are shared among all applications. The load rate for the next time slot is predicted by using a prediction algorithm. Based on this prediction, the resource in the pool is allocated to applications in a way that satisfies the demand while optimizing the energy consumption. All machines not on demand are turned off or placed in sleep mode to save energy. In theory, this is the most energy efficient resource allocation model for data centers, however, applying this model to data centers like ENI's faces many difficulties. To apply the resource on demand model, the data center needs many people to do the deployment/redeployment tasks when the load rate changes. If all thousands of applications need adjustment, the data center cannot have enough people to do this.

The work in [64] builds an integrated framework for energy savings in large scale distributed systems such as grids and clouds. The authors discussed several techniques such as defining different policies for OAR [65], power off idle nodes, predicting the future load, etc., to save energy in grid and cloud environment. Our work is different from the work of [64] in several fundamental aspects. We focus on developing a green IT implementation framework that considers both energy efficiency and green house gases into account for building environment friendly data centers and framework should be easy to implement and cost effective.

4. Proposed energy efficiency and low carbon enabler green IT framework

Green IT is an organization's ability to systematically apply environmental sustainability criteria (such as pollution prevention, product stewardship, use of clean technologies) to the design, production, sourcing, use and disposal of the IT technical infrastructure as well as within the human and managerial components of the IT infrastructure [2]. The rise of the green movement has been a long time; perhaps the oil shortage and record gas prices mainstreamed the challenge for all business enterprises and government agencies. Regardless of how we finally reached this point in time, there is little argument that we are here. The environment and sustainable energy have become a hot topic of conversation everywhere from kitchen tables to political arenas. It is no secret that the environmental movement has reached mass acceptance as leading publications across the globe have put environmental issues on their covers in an effort to raise awareness. Whether driven by consumer demand, economics, politics, legislative mandate, or even corporate social responsibility objectives, the green movement has caught on and corporations across the globe are beginning to embrace it with open arms [10].

The proposed framework does not only provides understanding of different aspects of Green IT, but can be used as a tool to evaluate the techniques needed to put Green IT into action, and to find out which departments out of Strategy, IS/IT or Operations would figure most heavily in data center's pursuit of 'greening' efforts. As a continuing valuation tool, the framework acts both as a strategic Green IT implementation bridge, and as an interval reference point, for policy-making and strategic goal progression.

The proposed Green IT implementation framework consists of five steps to be followed to properly implement virtualization and cloud computing solutions in data centers at different layers and then helps to identify and employ green metrics to measure the efficiency of data center in terms of energy efficiency and CO_2 emissions. The proposed Green IT framework using green metrics should be used and followed by data center managers to implement green initiatives in their data center to make it more energy efficient and green. It consists of following five phases (Figs. 4 and 5).

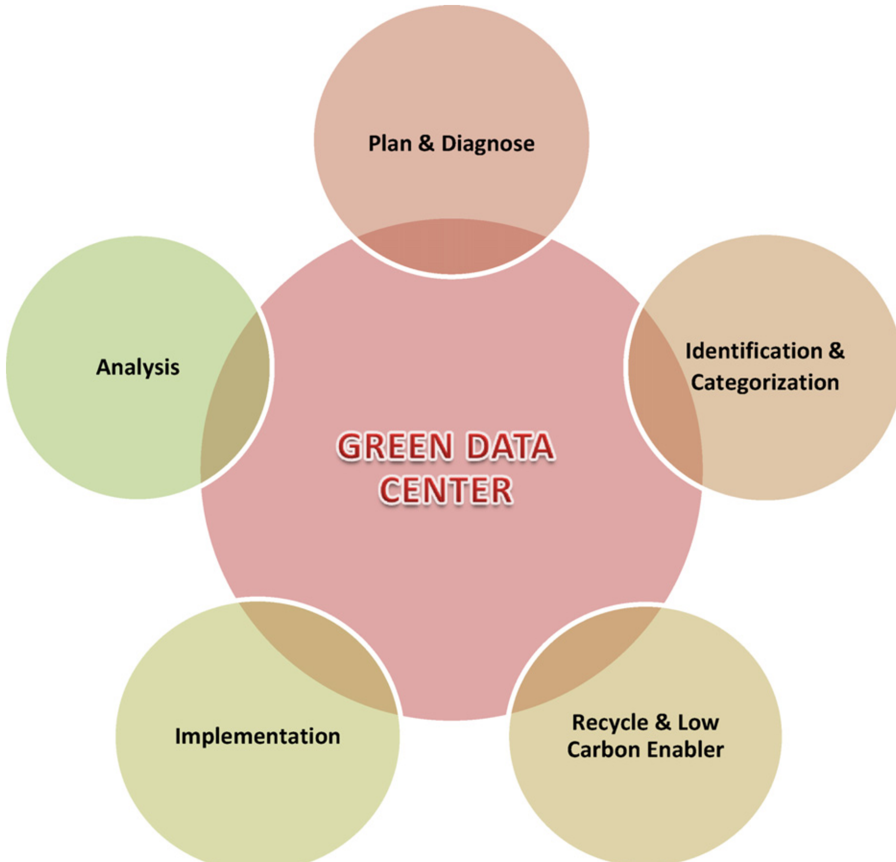

Fig. 4. Phases of proposed green IT framework.

4.1. Planning phase

The first step in developing Green IT Framework is to identify current awareness of Green IT initiatives in all tiers of data center industry as they are the largest server farms consuming huge amount of energy and generate enormous amount of CO_2 emissions very hazardous for environmental health and global warming. The next step is to identify best green IT practices like proper hardware utilization, live migration, server consolidation, installing energy efficient equipments, etc. that can be implemented in these data centers considering cost and other issues to achieve energy efficient data centers. This phase also consists of establishing efficiency teams and then assigning goals to be achieved. This phase is subdivided into following categories

1. Identify current Green IT Initiatives in data centers
2. Identify best practices and potential advantages for implementing green data centers
3. Establish efficiency teams and goals

4.2. Identification and categorization phase

Data centers are huge entities consists of many different components and devices performing different tasks to meet the end user needs. These components should be categorized into measurable resource pools depending on the workloads they execute, so that green metrics can be applied to measure their performance and efficiency individually and then to find out the overall efficiency of data center, because it is difficult to manage and measure the efficiency of whole data center collectively. Some of the major data center components are listed below.

- Servers
- Storage Devices
- Uninterruptible power supplies (UPS)
- Switch gear
- Chillers
- Computer room air conditioners
- Direct expansion (DX) units
- Pumps
- Cooling tower
- Generators
- Distribution losses external to the racks
- Power distribution units (PDUs)
- Batteries
- Lighting, etc.

4.2.1. Categorize data center into measurable units

A complete benchmark specifies three things: a workload to run, which should represent some real-world task of interest; a metric or score to compare different systems; and operational rules to ensure that the benchmark runs under realistic conditions. For a metric to run properly there is a need to categorize data center into measurable units. Currently there is no proper mechanism available to categorize data center components into measurable units so that energy efficiency metrics can be applied to separately measure their performance either individually or as whole. This process helps data center managers to properly categorize workloads depending on the processing they perform. This paper proposes a Metrics based energy efficiency model to categorize data center into measurable units and then applied green metrics available so that efficiency can be measured and benchmarking can be set. The categorization helps

Fig. 5. Energy efficiency and low carbon enabler green IT framework for data centers.

data center managers to identify and apply appropriate metrics against the workloads so that benchmarking values can be set (Fig. 6).

4.2.1.1. Metrics based energy efficiency model. The major barrier in improving energy efficiency in data center is the lack of appropriate metrics. This paper proposes what metrics could a company or an organization use to measure the effectiveness of their green initiatives for energy savings in the data center? It also provides IT managers with two most important industry acceptable metrics Power Usage Effectiveness (PUE) and its reciprocal, Data Center Efficiency (DCE) and Data Center Productivity DCP. These metrics enables data center operators to quickly estimate the energy efficiency of their data centers, compare the results against other data centers, and determine if any energy efficiency improvements need to be made.

To mitigate the problems associated with a multitude of metrics and thereby inconsistent measurements of data center performance, the US department of energy DOE and EPA conducted a workshop in July 2008 regarding the collaboration between the government and IT industry to improve energy efficiency in data centers [66]. The areas of improvement discussed include:

1. Defining energy efficient data centers, creating better transparency in the energy use in data centers and IT equipment through metrics, standards and best practices.
2. Advancing energy efficient data centers: focusing on adoption of energy efficient technologies and practices in data centers through knowledge creation and management.
3. Rewarding energy efficient data centers to help organizations better quantify and understand internal rewards from energy efficiency.

To achieve some of the objectives highlighted above, Interviews were conducted from top managers including directors from IT data centers operations, environmental initiatives and enterprise infrastructures. The survey results from the interviews are then normalized and it seemed surprising that performance and cost were the most important attributes. Form these surveys it was found that three industry metrics Server consolidation, Power management and data center cooling were considered important. From these results it was also found that managing capital costs and operating expenses are the vital to a company's viability. But due to the lack of appropriate metrics it becomes difficult for IT managers to measure the cost and performance of data centers to make them energy efficient and green.

This paper proposes a model which categorizes data center components into layers and then applies green metrics discussed

Fig. 6. Categorization of data center into measurable units.

earlier to achieve the desired results. A good metric would be something that measures the efficiency, the sustainability and the cost of a green initiative. The biggest problem any metrics faces when applied for calculating energy efficiency is the lack of standardized system of categorizing different resources of data center. The proposed model identifies different hardware components that need to be measured for energy efficiency and then creates a relationship between these hardware components and creates a relational layer between them. The first step in developing the model is to identify the components and then group them in different categorizes according to their measurement efficiency and workloads. As this research mainly focuses on calculating energy efficiency and carbon footprints, i.e., CO_2 emissions, so devices related to power energy will be used for calculating energy efficiency.

The proposed model divides data center into four key areas so as to measure them separately. The areas considered are then grouped and these are: Energy consumption, Performance of the system, Space used within the facility and CO_2 emissions. These all elements are arranged in a layer called Services layer. After that a component layer will be developed beneath the Services layer which consists of small components from top layer elements. For example under Energy consumption, there are subcategories like IT power and Facilities power and under these are further sub components like Server, Network and storage Power. Each of these components has an associated set of metrics that deal solely with that component. Each element in the component layer is identified in the model with a blue rectangle. The metrics found relate the major modules of the system include PUE, DCP and CEC [67]. These metrics sum up the relationships between major constituents of the data center. This is the relational layer and is associated with the green boxes in the model. This model can be useful in communicating the management of energy efficiency outside of the IT organization. The metrics used in the relational layer (green boxes) are the ones that would typically be communicated to the corporate ranks on a continuing basis.

The proposed model uses the following phases to categorize data center into measurable units. These phases are:

1. Inventory Process (identify and Classify DC equipments according to some criteria)
2. Categorize workloads

A. Inventory Process

The inventory process identifies and classifies all the components of a data center and classifies them according to different parameters like energy use, carbon emission, utility ratio, type of equipment, life time, etc.

The data center inventory process classifies all equipments into two major categories:

Total Facility Power
IT Equipment Power

Total Facility Power

It is defined as the power measured at the utility meter. This power is dedicated solely to the data center. It includes everything that supports the IT equipment components such as (Fig. 7):

Power Delivery Components such as:

- Uninterruptable Power Supply
- Switch gear
- Generators
- Power Distribution Units
- Batteries
- Distribution losses external to the IT equipment

Cooling System Components such as:

- Chillers
- Computer room air conditioning units (CRACs)
- Direct expansion air handler (DX) units
- Pumps
- Cooling towers
- Other miscellaneous components such as data center lighting, etc.

Cooling System Components such as:

- Chillers
- Computer room air conditioning units (CRACs)
- Direct expansion air handler (DX) units
- Pumps
- Cooling towers

Other miscellaneous components such as data center lighting, etc.

IT Equipment Power

The IT Equipment Power is defined as the equipment that is used to manage, process, store, or route data within the raised floor space in the data center. It includes the components associated with all of the IT equipments, such as:

Computing Equipments such as:

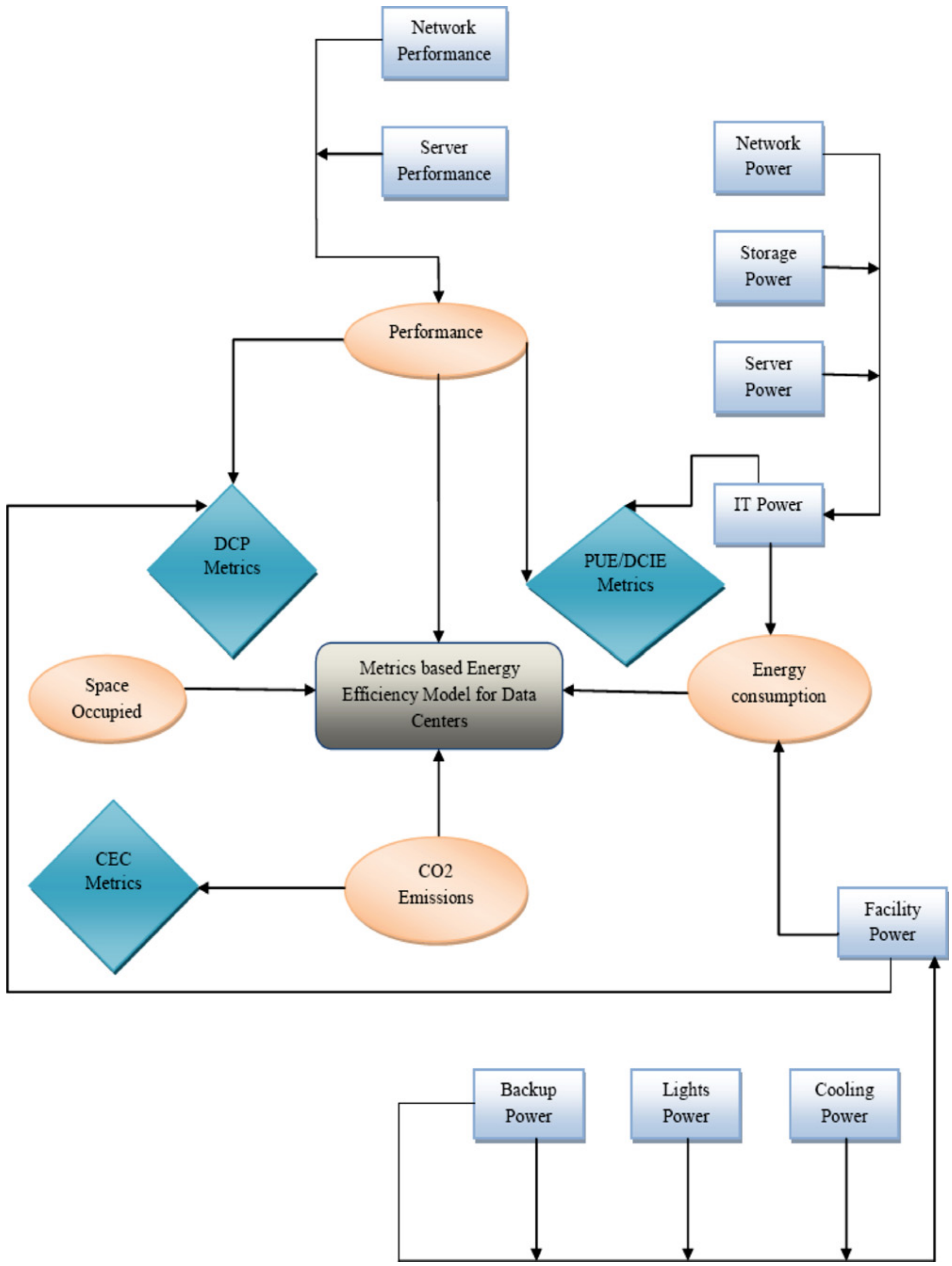

Fig. 7. Metrics based energy efficiency model.

- Server Machines
- Client Machines
- Network equipments
- Storage equipments
- The decreased efficiency of UPS equipment when run at low loads

Supplementary Equipments such as:

- KVM switches
- Monitors
- Workstations/laptops used to monitor or otherwise control the data center

B. Categorize Workloads

After inventory process categorize workloads according to their usage and resource requirements. Servers are the major components performing most of the processing so they should be categorized according to the services they provide and resources they require in order to process the requests.

In a traditional data center, each server is devoted to a specific function. For instance, an e-mail server deals only with e-mail and a payroll server handles only payroll. But this traditional way is inefficient because the e-mail server could only run at 65% capacity, for instance, during business hours to accommodate spikes in demand. And the same server would uses significantly less energy during non business hours. The payroll server, on the other hand, might run at only 5 percent capacity during business hours as a few changes and queries are processed by personnel, holding the remainder of its capacity in reserve for the larger job of payroll processing after hours. Using virtualization, the e-mail server and payroll server could share the same machine, with e-mail processing using the bulk of the capacity during business hours and payroll processing using the bulk during off hours. Using this method, governments purchase and maintain less equipment. They also

save on the cost of housing, powering and cooling huge server farms that only use a fraction of their processing power. Bringing all of a government's processing needs together under one roof can bring immense efficiency and cost benefits to the government organization. A single data center also gives organizations more flexibility to align their processes with their goals especially when services-based approaches, such as SOA, and an increased use of industry standards begin bridging and breaking down information silos.

C. Categorize Server Resources

After creating server inventory information, the next step is to categorize the servers and their associated resources and workloads into resource pools. This process is performed to avoid any technical political, security, privacy and regulatory concern between servers, which prevent them from sharing resources. Once analysis is performed, we can categorize each server roles into groups. Server roles are categorized into following service types [68]:

- Network infrastructure servers
- Identity Management servers
- Terminal servers
- File and print servers
- Application servers
- Dedicated web servers
- Collaboration servers
- Web servers
- Database servers

D. Categorizing Application Resources

After categorizing servers into different resource pools, applications will also be categorized as:

- Commercial versus in-house
- Custom applications
- Legacy versus updated applications
- Infrastructure applications
- Support to business applications
- Line of business applications
- Mission critical applications

E. Allocation of Resources

After creating the workloads, the next process is to allocate computing resources required by these different workloads and then arranging them in normalized form, but for normalization the processor utilization should be at least 50%. It is very important to normalize workloads so as to achieve maximum efficiency in terms of energy, cost and utilization. The formula proposed in this paper for normalization is to multiply utilization ratio of each server by total processor capacity that is (maximum processor efficiency $\times$ number of processors $\times$ number of cores).

Servers are the major consumers of energy as they are in huge quantity and perform most of the processing. If we apply different efficiency calculators to calculate different efficiencies like energy efficiency and CO_2 emissions then, there must be a mechanism to categorize these different devices into different categories so that they can easily be evaluated and measured. But unfortunately there is no standard mechanism available to categorize these devices according to some criteria [69].

F. Server Categorization

Mueen proposed a technique through Server Consolidation to increase the utilization of already installed devices especially servers to increases the utilization ratio up to 50% or even higher which saves energy and cost and at the same time reduces the emission of green house gases hazardous for global warming [8]. The proposed technique divides the underutilized volume servers into three categories on the basis of workloads these servers perform and applications they execute. These classifications may vary from business to business with different infrastructures and requirements, as servers are generally used to create, maintain and execute solutions on the behalf of businesses, architectures, processes and infrastructures. After categorizing, server consolidation is applied on all categories of servers depending on their utilization ratio in the data center. This process reduces the number of servers by consolidating the load of multiple servers on one server. It also increases the utilization ratio of servers. These categories are:

1. Innovation Servers
2. Production Servers
3. Mission Critical Servers

4.2.2. Identify green metrics and set benchmarking

After categorization the next step is to identify the suitable metrics for benchmarking. But unfortunately due to the lack of both standard metrics and benchmarking formulas there is no industry metrics available to calculate both efficiencies, i.e. (energy and carbon footprints) at the same time using the same tool. Many metrics have been proposed to quantify various aspects of data center energy efficiency, from the building's power and cooling provisioning to the utilization of the computing equipment.

To quantify the power efficiency of data centers, a metric such as the Power Usage Effectiveness (PUE) has been proposed. The PUE is defined as the total power used by the data center divided by the total power consumed by the ICT equipment. PUE can be used to benchmark how much energy is being usefully deployed versus how much is wasted on overheads. Typical data centers today have a PUE of about 2 or higher. By carefully operating much of the current equipment in use and by using the latest hardware and software technologies, the Environmental Protection Agency (EPA) predicts this PUE number can be reduced to 1.7 and 1.2, respectively.

The Uptime Institute identified a variety of metrics contributing to data center "greenness," including measures of power conversion efficiency at the server and data center levels, as well as the utilization efficiency of the deployed hardware. To optimize data center cooling, Chandrakant Patel and others have advocated a metric based on performance per unit of *exergy* destroyed [70] (Fig. 8).

Exergy is the available energy in a thermodynamic sense, and so exergy aware metrics take into account the conversion of energy into different forms. In particular, exergy is expended when electrical power is converted to heat and when heat is transported across thermal resistances. The Green Grid, an industrial consortium including most major hardware vendors, has proposed several metrics to quantify data center power efficiency over both space and time. To quantify space efficiency, they define the Data Center Density (DCD) metric as the ratio of the power consumed by all equipment on the raised floor to the area of the raised floor, in units of kilowatts per square foot [71]. To quantify time efficiency (that is, energy efficiency), the Data Center Infrastructure Efficiency (DCiE) metric will be used. DCiE is defined as the percentage of the total facility power that goes to the "IT equipment" (primarily compute, storage, and network). Since IT equipment power is not necessarily a proxy for performance, two extensions of this metric have been proposed. Compute Power Efficiency (CPE), proposed by Malone and Belady, scales the DCiE by the IT equipment utilization, a value between 0 and 1 [72]. With this metric, the power consumed by idle servers counts as overhead rather than as power that is being productively used. Similarly, the Green Grid has introduced the Data Center Energy Productivity metric (DCeP), which is the useful work divided by the total facility power [73]. This metric can be applied to

Fig. 8. Identify green metrics and set benchmarks.

Fig. 9. Identify virtualization and cloud computing type.

any data center workload. None of these data center metrics specifies a workload, and most do not take any measure of performance into account.

4.2.3. *Identify virtualization and cloud computing type*

It is very important for an organization to know in advance the total content of its infrastructure before implementing virtualization. This is the most important step in any virtualization project. There are many tools available from different vendors for performing initial analysis of an organization [68] (Fig. 9).

Microsoft Baseline Security Analyzer (MBSA) tool provides different information like IP addressing, Operating System, installed applications and most importantly vulnerabilities of every scanned system. After analyzing, all generated values are linked to MS Visio, which generates a complete inventory diagram of all components and also provides details about each component being analyzed. Microsoft Assessment and Planning toolkit (MAP) is another tool for the assessment of network resources. It works with windows management instrumentation (WMI), the remote registry service or with simple network management protocol to identify systems on network. VMware, the founder of X-86 virtualization, also offers different tools for the assessment of servers that could be transformed into virtual machines. VMware Guided Consolidation (VGC) a powerful tool assesses network with fewer than 100 physical servers. Since VGC is an agent less tool it does not add any overhead over production server's workload.

To properly implement virtualization we proposed a detailed layered virtualization implementation model consisting of five layers. Each layer defines more detailed processes needed for proper implementation of virtualization technology in data centers at different levels considering infrastructure and costs. These components provide a detailed treatment of state of the art and emerging challenges faced by data centers managers to implement and manage virtualization properly in their data centers to achieve desired objectives. The proposed model defines that, the process of virtualization should be structured and designed in such a way that it must fulfill the necessary requirements and should be within the scope and infrastructure domain already installed in the data center. It is therefore much more than simply loading a

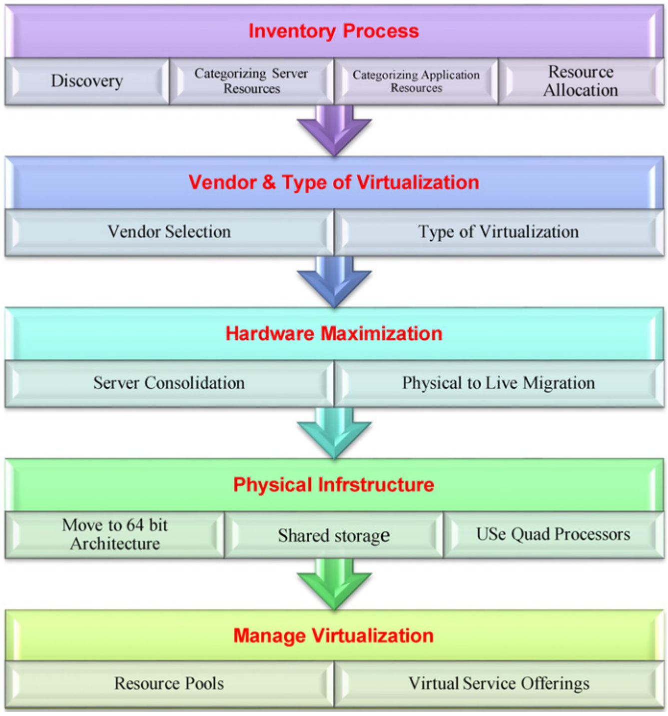

Fig. 10. Virtualization implementation process.

virtualization technology on different servers and transforming one or two workloads into virtual machines. Rather it is a complex and rigorous process that need to be implemented and monitored properly [74]. The proposed model defines five key steps need to be followed at different stages in a structural way to achieve the efficiency required in the data center. The components of proposed model are listed below (Fig. 10):

- Inventory Process
- Vendor and of Virtualization
- Hardware Maximization
- Physical Infrastructure
- Manage Virtualization

The reasons to consolidate and virtualize IT infrastructure, i.e. server are wide-ranging. Mostly IT managers focus on just the cost of the physical IT infrastructure, but there are many additional benefits that can be derived from Server consolidation like:

- Proper Utilization of Servers
- Proper energy utilization
- Reduction in consumption of energy
- Reduction in emission of green house gases
- Reduction in global warming effects
- Achieving sustainable businesses
- Simplified management
- Improved data protection
- Improved resource utilization
- Easier revision control and flexibility
- Easier data protection and security
- Reduced server and software costs, etc.

Servers are the major consumers of energy and they need to be consolidated using virtualization. This process comprises of following sub phases:

1. Categorize Server Resources [8]
2. Select vendor (VMware, Citrix, Microsoft, etc.)
3. Apply Server Consolidation [8]

4.3. *Recycling and low carbon enabler policy*

The 3rd phase of framework covers the major component of greening data centers. It covers the acquisition and procurement of data center equipments, and disposal or recycling at the end of its lifecycle in an environmentally responsible fashion. It also implies that carbon emissions should be reduced by formulating a policy based on green metrics that measure the emission of green house gases from data centers at regular intervals. Data center equipment, like all other equipment, passes through a lifecycle. It is manufactured, sold (and for every sale there is a purchase), used and often reused, and then ultimately disposed of. That disposal may mean it is discarded or destroyed, but it may also be sold or given to another person or organization, where it has another lifecycle contained within its larger lifecycle.

4.3.1. *Procurement*

Procurement is arguably the most important aspect of green data center in terms of making an overall impact on sustainability; it defines the limit or amount of energy spent in manufacturing and what it consumes in its lifetime. There are two aspects to green procurement.

- The nature of the equipment itself
- The nature of the suppliers of that equipment.

The equipment an organization purchases may comply with environmental standards such as Energy Star and the Electronic Product Environmental Assessment Tool (EPEAT). However, consideration should also be given to the suppliers' own green strategies and carbon footprint. This includes such things as the supplier's environmental values in the design and manufacture of equipment and how it measures them, its compliance with relevant environmental laws and codes of practice, and whether the supplier reclaims and recycles old equipment from customers. Organizations are increasingly developing policies for measuring the environmental performance of their ICT suppliers. The degree of energy efficiency, product life-cycle emissions and the level of waste associated with any procured equipment are becoming important purchasing factors. In addition to the usual criteria of price, performance and service levels, tenders and requests for proposals (RFPs) are also often evaluating suppliers on their environmental credentials and asking for details of their own green practices and policies. To reduce waste, some organizations will only buy from suppliers that will deliver their equipment, unpack and take the packaging away with them.

4.3.2. *Recycle and disposal*

All data center managers must replace their ICT equipment periodically. Some have regular refresh cycles, some wait till they have to, and some utilize some sort of continuous update process (especially with software). This is a natural aspect of the ICT function. But many organizations replace equipment too early, often through a fear of not being able to run the latest versions of software. This can create unnecessary waste and expenditure as few organizations always need the latest versions of hardware and software to function adequately.

Even when it is time for a system upgrade, it may not be necessary for the whole enterprise. Areas of the data center that really do need new equipment may be able to pass on their old equipment to other parts, perhaps those with less mission critical activities. Any equipment that conforms to the organization's hardware standards

and that can run a version of software the vendor still supports, is potentially redeploy able. The recycling policy should implement 3R's policy to properly recycle all data center equipments.

A. Reduce

Buy only what you need. Purchasing fewer goods means less to throw away. It also results in fewer goods being produced and less energy being used in the manufacturing process. Buying goods with less packaging also reduces the amount of waste generated and the amount of energy used.

B. Reuse

Buy products that can be used repeatedly. If you buy things that can be reused rather than disposable items that are used once and thrown away, you will save natural resources. You'll also save the energy used to make them and reduce the amount of landfill space needed to contain the waste.

C. Recycle

Make it a priority to recycle all materials that you can. Using recycled material almost always consumes less energy than using new materials. Recycling reduces energy needs for mining, refining, and many other manufacturing processes. Recycling a pound of steel saves enough energy to light a 60-watt light bulb for 26 hours. Recycling a ton of glass saves the equivalent of nine gallons of fuel oil. Recycling aluminium cans saves 95 percent of the energy required to produce aluminium from bauxite. Recycling paper reduces energy usage by half.

4.3.3. Energy efficiency and CO_2 measurement tools and performance metrics

PUE is a widely used metric to quantify the power efficiency of data centers. Today, energy efficiency has become an important metric that is being increasingly used to evaluate the energy consumption of devices, hardware, software, and various networking architectures, systems, and communication protocols. Many energy efficiency metrics for networking protocols and devices have been proposed in the past, but most of them have been specialized for specific networking software or equipment and are being used in an ad-hoc way. For instance, typical ones used in the literature include absolute power in watts, power per bit, and normalized energy consumption (sum of energy consumed by all components) to full-duplex throughput for networking devices [75]. Unfortunately, the lack of standard energy efficiency metrics makes energy performance comparisons for networking devices and protocols hard to achieve in practice. In the future, to help networking designers, implementers, application developers, and researchers better assess and evaluate the energy efficiency of their implementation prototypes; we need to standardize a set of energy efficiency metrics with a finer granularity that takes into account diverse processing functions and configurations. Similarly, we found there is also a lack of energy performance tools that can be used to measure energy efficiency of networking devices, systems, protocols, and applications. There are a few commercial highly sophisticated power measurement tools available, but they are prohibitively expensive. A few cost-effective tools are also available on the market (e.g., the Kill A Watt EZ tool that can be connected to an appliance and measures its power usage). But they are of limited use for serious energy efficiency research purposes given their coarse measurements of electricity used.

Other freeware energy measurement tools recently experimented with Joulemeter (estimates the power used by one's computer) from Microsoft Research and the Intel's Application Energy Toolkit (used to evaluate power consumption of software applications). We found that, while these tools are fairly easy to use and they do provide some basic power consumption information (e.g., battery usage, voltage, etc.), they are not user friendly as far the processed output results are concerned or sometimes even the output data would be corrupted and required the tests to be repeated, etc. In short, we need far more efficient, easy-to-use, low-cost energy performance tools that researchers and designers can easily use to conduct robust energy performance evaluations of their prototype systems.

4.4. Implementation phase

The fourth phase of Green IT implementation framework deals with actual implementation of Green IT initiatives by data center managers. It is important to highlight the importance of infrastructure and cost needed for implementing the necessary measures tinted in previous phases. This phase consists of following five sub phases:

- Revamp Architecture and Infrastructure
- Implement Virtualization and Cloud Computing with Outsourcing
- Improve Utilization of IT Equipment
- Apply Metrics Selected to Measure Efficiency
- Select Benchmarking Values

4.5. Analysis phase

This Phase deals with measuring the performance of data center regularly from time to time using the metrics selected; this is done by performing the following two steps:

1. Collect data at regular time intervals(Facilities data, Infrastructure data, IT Equipment data)
2. Perform analysis using energy and CO_2 efficiency Calculators
3. Compare New Values with Older Baseline Values
4. Standardize Benchmark Values
5. Look For Greener Solutions and Continue Greening Process

In this phase data center managers need to collect data regularly related to energy usage, carbon emissions, utilization ratio, life span, etc. of all categories of equipments from data center. After collecting data, analysis will be performed by using different tools like SPECpwer_ssj [76]. This tool will generate outputs on the basis of comparison between performance and power. This process should be repeated until maximum efficiency in terms of power to performance is achieved.

5. Conclusion

In recent years, energy efficiency has emerged as one of the most important design requirements for modern computing systems, such as data centers, as they continue to consume enormous amounts of electrical power. Apart from high operating costs incurred by computing resources, this leads to significant emissions of carbon dioxide into the environment. For example, currently IT infrastructures contribute about 2% of total CO_2 footprints. Unless energy-efficient techniques and algorithms to manage computing resources are developed, IT's contribution in the world's energy consumption and CO_2 emissions is expected to rapidly grow. The power management problem becomes more complicated when considered from the data center level. In this case the system is represented by a set of interconnected computing nodes that need to be managed as a single resource in order to minimize the energy consumption. This is obviously unacceptable in the age of climate change and global warming. This paper proposes a Green IT Framework using virtualization technology and green metrics to achieve power and energy efficiency in data centers. It is an implementation framework for data center managers to properly implement green IT technologies in their data centers. It comprises of five phases with

each phase describing the steps needed for proper implementation of green IT technologies in data centers.

The framework provides an imminent solution to the data center managers to improve the performance of their existing data centers by implementing the proposed energy efficiency low carbon enabler framework using green metrics. It also helps to reduce the emission of green house gases so that global warming effects can be reduced.

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